

## Introduction to Modeling and Simulation

### Accessing Share Drive

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# Introduction

Course Notes for:

## Introduction to Modeling and Simulation

Dr. Edwin Z. Crues

Simulation and Graphics Branch  
Simulation, Robotics and Software Division  
Engineering Directorate  
NASA Johnson Space Center

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# Topics

- Motivation
- History
- Ontology
  - Types
  - Usage
  - Classification
  - Application Domains
- Glossary

# Motivations

*(What is a model?)*

- “In the most general sense, a model is anything used in any way to represent anything else.” (Wikipedia)
- Wikipedia distinguishes between physical and non-physical models
  - 15 Entries for physical models
  - 22 Entries for non-physical models
- For this course, we'll be focusing on non-physical models

# Motivations

## *(What is a model? - Continued)*

- Abstract Models
  - Conceptual Model:

“The term conceptual model may be used to refer to models which are represented by concepts or related concepts which are formed after a conceptualization process in the mind. Conceptual models represent human intentions or semantics. Conceptualization from observation of physical existence and conceptual modeling are the necessary means human employ to think and solve problems.” (Wikipedia)
  - Mathematical Model:

“A mathematical model is a description of a system using mathematical concepts and language.” (Wikipedia)
- Applied
  - Computer Model:

“A computer simulation, a computer model, or a computational model is a computer program, or network of computers, that attempts to simulate an abstract model of a particular system.” (Wikipedia)

# Motivations

*(What is a model? - Continued)*

- “[A model is] a system of postulates, data, and inferences presented as a mathematical description of an entity or state of affairs.” (Merriam-Webster)

# Motivations

*(What is a Simulation?)*

- Simple
  - The process of executing a model is often referred to as simulation.
- More Formal
  - “Simulation is the imitation of some real thing available, state of affairs, or process. The act of simulating something generally entails representing certain key characteristics or behaviors of a selected physical or abstract system.” (Wikipedia)
  - “[Simulation is] the imitative representation of the functioning of one system or process by means of the functioning of another.” (Merriam-Webster)

# Motivations

*(Why Simulate?)*

- Need to answer questions but cannot use or don't have access to the “real” system
- System may not exist (yet)
- System or problem is too complex to analyze analytically
  - Highly non-linear
  - Many variables
- Need to look at many variations
  - Monte Carlo

# History

- Historical times

- War games

- Roman Empire



- Physical models

- Leonardo da Vinci



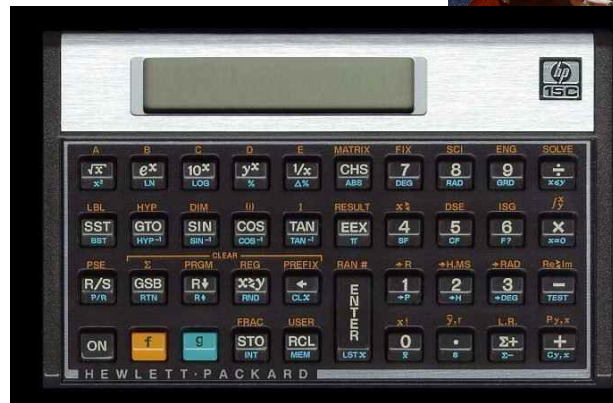
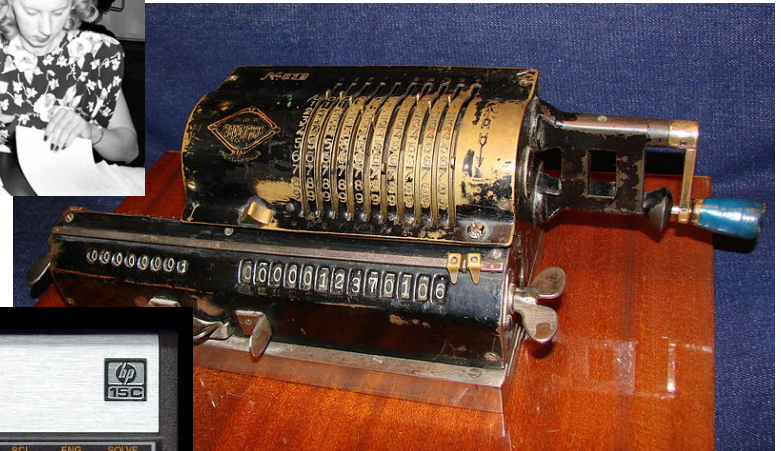
- Mathematical models

- Navier-Stokes

$$\rho \left( \frac{\partial \mathbf{v}}{\partial t} + \mathbf{v} \cdot \nabla \mathbf{v} \right) = -\nabla p + \nabla \cdot \mathbb{T} + \mathbf{f},$$

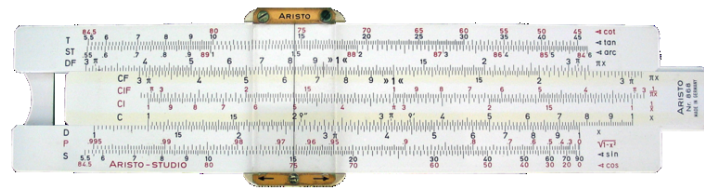
# History (Continued)

- Calculators
  - Human
  - Mechanical
  - Electronic

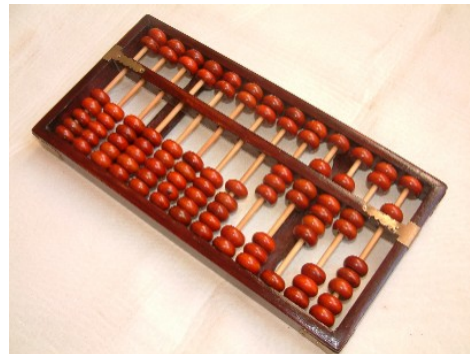


# History (Continued)

- Computers
  - Analog



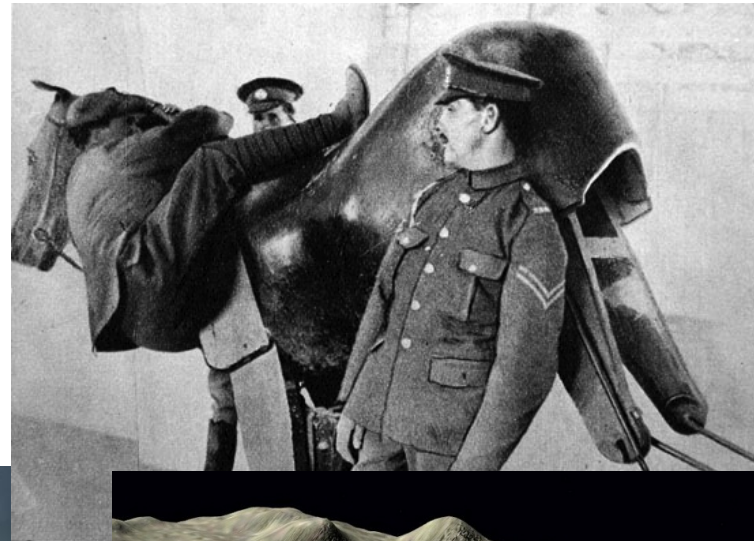
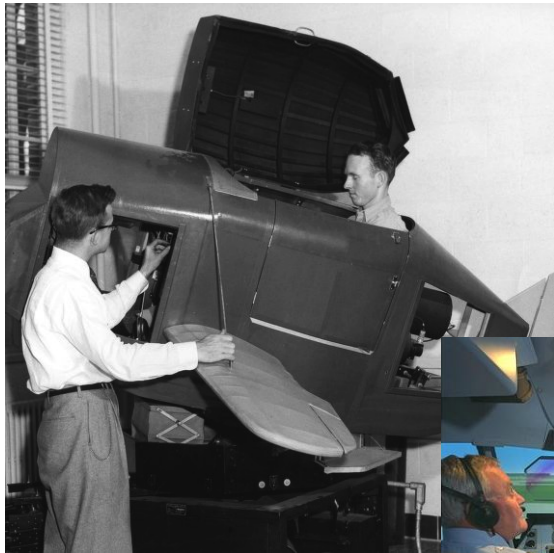
- Digital



# History

## *(Continued)*

- Simulators



# M&S (Modeling & Simulation) Ontology

- An ontology formally represents knowledge as a set of concepts within a domain, and the relationships between those concepts.  
(Wikipedia)
- Let's look at various ways of “categorizing” modeling and simulation.
  - Types
  - Usage
  - Classification
  - Application Domains

# M&S Ontology

## *(Types)*

- Parametric
  - A modeling of a system that can be characterized by a finite set of identifiable variables (parameters).
- Discrete Event
  - A modeling of a system represented as a chronological sequence of events. Each event occurs at an instant in time and marks a change of state in the system.
- Continuous
  - A modeling of a system that continuously tracks system response over time according to a set of equations typically involving differential equations.

# M&S Ontology

## *(Usage)*

- Analysis
  - Modeling or simulation performed for the purpose of investigating the behavior of a system of phenomenon.
- Design
  - Modeling or simulation performed in support of the construction or development of a product or system.
- Training
  - Modeling or simulation performed to teach, instruct or exercise.

# M&S Ontology

## *(Classifications)*

- Live
  - M&S involving real people operating real systems.
- Virtual
  - M&S involving real people operating simulated systems.
- Constructive
  - M&S involving simulated people operating simulated systems. Real people stimulate (provide inputs) to such simulations, but are not involved in determining the outcomes.

# M&S Ontology

*(Common Application Domains)*

- Science & Engineering
- Bio-medical and Health Services
- Transportation
- Energy
- Education
- Defense
- Aerospace
- Communications
- Process Control
- Manufacturing

# Basic M&S Glossary

- **Abstraction:** The process of selecting the essential aspects of a reference system to be represented in a model or simulation while ignoring those aspects that are not relevant to the purpose of the model or simulation (adapted from Fidelity ISG Glossary, Vol. 3.0).
- **Accuracy:** The difference between a parameter or variable (or a set of parameters or variables) within a model, simulation, or experiment and the true value or the assumed true value.
- **Accreditation:** The formal certification that a model or simulation is acceptable to be used for a specific purpose.
- **Analysis:** Any post-processing or interpretation of the individual values, arrays, files of data, or suites of executions resulting from a simulation.
- **Artifact:** Any tangible product that is produced by the project team, i.e., requirements document, help system, code, executable, test documentation, test result, diagram, etc.
- **Calibration:** The process of adjusting numerical or modeling parameters in the model to improve agreement with a referent.

*From NASA Technical Standard 7009 – Standards for Modeling and Simulation*

# Basic M&S Glossary

## *(Continued)*

- **Computational Model:** The numerical representation of the mathematical model.
- **Conceptual Model:** The collection of abstractions, assumptions, and descriptions of physical processes representing the behavior of the reality of interest from which the mathematical model or validation experiments can be constructed (adapted from ASME V&V 10).
- **Configuration Management (CM):** A management discipline applied over the product's life cycle to provide visibility into and to control changes to performance, functional, and physical characteristics (NPR 7120.5D, NASA Space Flight Program and Project Management Requirements).
- **Credibility:** The quality to elicit belief or trust in M&S results.
- **Critical Decision:** Those technical decisions related to design, development, manufacturing, ground, or flight operations that may impact human safety or mission success, as measured by program/project-defined criteria.
- **Emulation:** The use of a model or simulation to imitate another system, so that the model or simulation behaves like or appears to be the other system.

*From NASA Technical Standard 7009 – Standards for Modeling and Simulation*

# Basic M&S Glossary

## *(Continued)*

- **Endorsement:** A formal assurance that a product, process, or service conforms to specified characteristics. (Examples of endorsement include “accreditation”—the official acceptance of a model or simulation and its associated data to use for a specific purpose—and “certification,” which is similar to accreditation, but often applies to a class of purposes or a general domain and generally implies an independent and/or third-party certifier.)
- **Human Safety:** The condition of being protected from death, permanently disabling injury, severe injury, and several occupational illnesses. In the NASA context this refers to safety of the public, astronauts, pilots and the NASA workforce (adapted from NPR 8000.4 and the NASA Safety Hierarchy).
- **Limits of Operation:** The boundary of the set of parameters for which an M&S result is acceptable based on the program/project-required outcomes of verification, validation, and uncertainty quantification.
- **Mathematical Model:** The mathematical equations, boundary values, initial conditions, and modeling data needed to describe the conceptual model (ASME V&V 10).

*From NASA Technical Standard 7009 – Standards for Modeling and Simulation*

# Basic M&S Glossary

## *(Continued)*

- **Mission Success Criteria:** Standards against which the program or project will be deemed a success. Mission success criteria may be both qualitative and quantitative, and may cover mission cost, schedule, and performance results as well as actual mission outcomes (NPR 7120.5C, NASA Program and Project Management Processes and Requirements).
- **Model:** A description or representation of a system, entity, phenomena, or process (adapted from Banks, J., ed. (1998). Handbook of Simulation. New York: John Wiley & Sons). (A model may be constructed from multiple sub-models; the sub-models and the integrated sub-models are all considered models. Likewise, any data that goes into a model is considered part of the model. A model of a model (commonly called a metamodel), e.g., a response surface constructed from the results of M&S, is considered a model).
- **Referent:** Data, information, knowledge, or theory against which simulation results can be compared (adapted from ASME V&V 10).

*From NASA Technical Standard 7009 – Standards for Modeling and Simulation*

# Basic M&S Glossary

## *(Continued)*

- **Risk:** The combination of the probability that a program or project will experience an undesired event and the consequences, impact, or severity of the undesired event, if it were to occur. Both the probability and consequences may have associated uncertainties (adapted from NPR 7120.5D).
- **Sensitivity Analysis:** The study of how the variation in the output of a model can be apportioned to different sources of variation in the model input and parameters (adapted from Saltelli and others, 2000).
- **Simulation:** The imitation of the characteristics of a system, entity, phenomena, or process using a computational model.
- **Stimulation:** The description of a type of simulation whereby artificially generated signals are provided to real equipment in order to trigger it to produce the result required for verification of a real-world system, training, maintenance, or for research and development.
- **Subject Matter Expert:** An individual having education, training, or experience in a particular technical or operational discipline, system, or process and who participates in an aspect of M&S requiring his/her expertise.

*From NASA Technical Standard 7009 – Standards for Modeling and Simulation*

# Basic M&S Glossary

## *(Continued)*

- **Tailoring:** The documentation and approval of the adaptation of the processes and approach to complying with requirements according to the purpose, complexity, and scope of a NASA program or project. (NPR 7123.1A, NASA Systems Engineering Processes and Requirements).
- **Uncertainty:** (1) The estimated amount or percentage by which an observed or calculated value may differ from the true value (The American Heritage Dictionary of the English Language, 4th ed.). (2) A broad and general term used to describe an imperfect state of knowledge or a variability resulting from a variety of factors including, but not limited to, lack of knowledge, applicability of information, physical variation, randomness or stochastic behavior, indeterminacy, judgment, and approximation (adapted from NPR 8715.3B, NASA General Safety Program Requirements).
- **Uncertainty Quantification:** The process of identifying all relevant sources of uncertainties, characterizing them in all models, experiments, and comparisons of M&S results and experiments, and of quantifying uncertainties in all relevant inputs and outputs of the simulation or experiment.

*From NASA Technical Standard 7009 – Standards for Modeling and Simulation*

# Basic M&S Glossary

## *(Continued)*

- **Validation:** The process of determining the degree to which a model or a simulation is an accurate representation of the real world from the perspective of the intended uses of the model or the simulation.
- **Verification:** The process of determining that a computational model accurately represents the underlying mathematical model and its solution from the perspective of the intended uses of M&S.
- **Waiver:** A documented authorization intentionally releasing a program or project from meeting a requirement (NPR 7120.5D). Deviations and exceptions are considered special cases of waivers.

*From NASA Technical Standard 7009 – Standards for Modeling and Simulation*